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A Multiple Armature Railgun Launcher

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EM guns have several launch characteristics that differ from conventional guns. Higher launch velocities are achievable in EM guns because sonic gas velocities do not limit the projectile velocity. Acceleration profiles for EM guns are more constant. The acceleration forces can be distributed on the projectile easily because the accelerating force can be distributed with multiple armatures. These characteristics combine to make EM guns a very attractive approach for launching very long (i.e., high L/D ratio) projectiles.

Railgun launchers with multiple armatures can distribute the accelerating force. Each armature is supplied gun current for acceleration through its own set of rails. This multi-rail, multi-armature concept was tested at the railgun test facility. The results demonstrated feasibility. We were able to control current distribution to multiple armatures. This paper describes the theory and test results for multi-armature launch of high L/D projectiles.

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PREFACE

This paper documents research conducted on multiple armature/rail railguns for accelerating long rod penetrators. It was presented at the6th Electromagnetic Launcher Conference in Austin TX on 28 April to 1 May 1992.

This work was funded by WL/MNSH of the Armament Directorate at Eglin AFB FL under the Kinetic Energy Weapons Program of the Strategic Defense Initiative. Mr. Mark W. Heyse, Mr. James B. Cornette, and Mr. Nolan E. Taconi from WL/MNSH and personnel from IAP Research, Inc. in Dayton OH performed the work during the period of August 1989 to April 1992 at IAP in Dayton OH.

A MULTIPLE ARMATURE RAILGUN LAUNCHER

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Abstract—As longer projectiles are accelerated, the efficiency (projectile mass/launch mass) of the launch package decreases. The reduction in efficiency makes launching projectiles with a L/D (length-to-diameter ratio) greater than 20 undesirable.

EM guns have several launch characteristics which differ from conventional guns. Higher launch velocities are achievable in EM guns because sonic gas velocities do not limit the projectile velocity. Acceleration profiles for EM guns are more constant. The acceleration forces can be distributed on the projectile easily because the accelerating force can be distributed with multiple armatures. These characteristics combine to make EM guns a very attractive approach for launching very long (i.e., high L/D ratio) projectiles.

Railgun launchers with multiple armatures can distribute the accelerating force. Each armature is supplied gun current for acceleration through its own set of rails. We tested this multi-rail, multi-armature concept at our railgun test facility. Our results demonstrated feasibility. We were able to control current distribution to multiple armatures. This paper describes the theory and test results for multi-armature launch of high L/D projectiles.

INTRODUCTION

High acceleration stresses make long, high aspect ratio projectiles difficult to gun launch. As longer projectiles are accelerated, the efficiency (projectile mass/launch mass) of the launch package gets worse. Sabots are used to transfer accelerating forces to the projectile during launch. As the launch package exits the gun, the sabot separates from the projectile. The sabot kinetic energy is wasted since it separates from the projectile at shot exit from the gun. Ideally, the sabot mass should be zero to minimize this wasted energy. Longer, higher aspect ratio projectiles require more sabot support to maintain acceptable projectile stresses. As projectile length increases the sabot size become so massive that a great deal of energy is wasted. It becomes inefficient to launch the package. Fig. 1 illustrates this point. The efficiency of the launch package mass decreases with an increase in projectile L/D ratio. This reduction in launch efficiency reduces the desirability to launch long projectiles. The key to launching long projectiles is to reduce sabot mass.

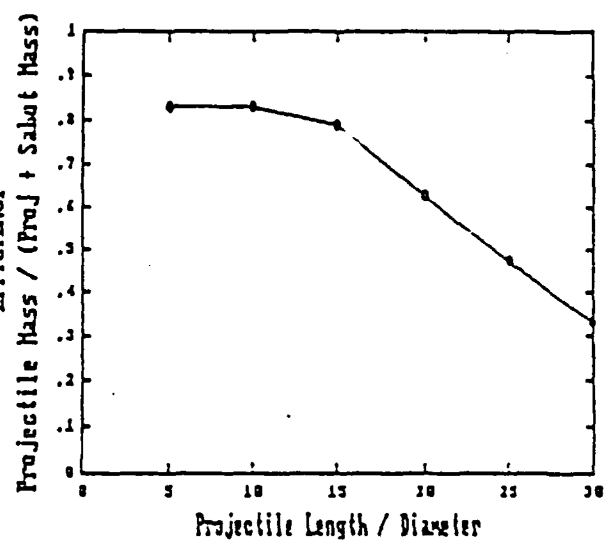

Fig. 1. The efficiency of single sabot launch packages decreases with an increase in projectile length.

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Normally, one sabot is used to accelerate a projectile. The sabot is designed to support most of the rod length. It transfers accelerating force via shear, all along the supporting interface. This interface is illustrated in Fig. 2(a). Here, portions of the rod are shown unsupported. The unsupported rod must be strong enough to withstand the tensile and compressive stresses due to acceleration. These stresses are highest at each end of the sabot, as Fig. 2(a) shows. For stronger rods or lower accelerations, the length of unsupported rod can be increased. With an increase in unsupported length, sabot size and mass shrinks.

A multiple sabot launch package improves launch package efficiency by reducing sabot mass. A multiple sabot package allows an increase in the length of unsupported rod. This is shown in Fig. 2(b). The multiple sabot package not only has both ends of the rod unsupported, it also enables unsupported length in the middle of the rod. Each segment of unsupported rod is sized to not exceed tensile and compression strength limit. The multiple sabot launch package allows us to reduce the total sabot mass compared to single sabot packages. Less energy is therefore lost due to sabot mass.

The use of multiple (two or more) sabots as shown in Fig. 2(b), can reduce sabot mass for long rods launched from any type gun. In conventional propellant guns however, it is difficult to adequately distribute the propellant gas pressure on more than one sabot. An electromagnetic (EM) railgun is not subject to the same limitations. EM forces can be distributed on multiple sabots by distributing current between sabots.

MULTIPLE ARMATURE/SABOT LAUNCH PACKAGE AND BARREL

Design

There is an optimum number of sabot/armatures for a specified long rod projectile [1]. However, in this paper we will focus on the two sabot configurations. We also assume that equal acceleration forces on the two sabots is desired. What is needed is an EM gun which provides controlled acceleration forces to multiple sabot/armatures (the armature is meant as the current carrying part of the sabot).

In an EM gun, the acceleration force (the Lorentz force) is due to the interaction of the current flowing in the armature with the magnetic flux density imposed on the armature [2]. This force may be expressed by:

$$F = I \omega \times B, \qquad (1)$$

where B = magnetic flux density,
I = armature current, and
ω = armature width.

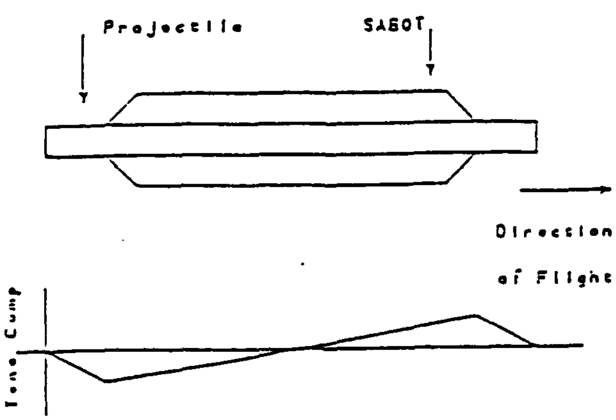

Fig. 2(a) A long rod, launched with a conventional single sabot, has high stresses as each end of the sabot.

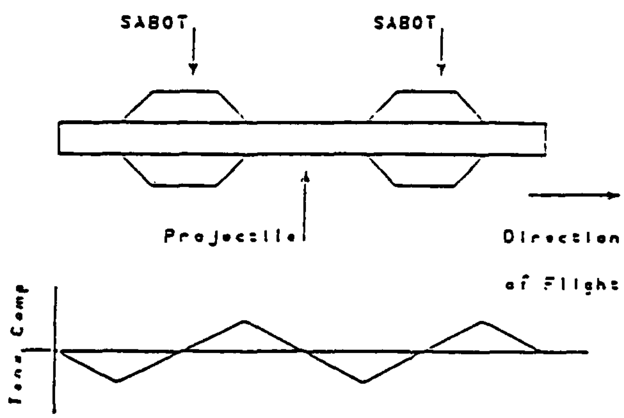

Fig. 2(b). Two sabots distribute launch loads causing high projectile stresses at four locations on the projectile.

Armature acceleration force is clearly controlled by magnetic flux density and armature current. Fig. 3 is a sketch of a two armature launch packages in a two-rail pairs railgun. This sketch identifies the current in each armature and the magnetic field imposed on each armature. The leading armature is similar to the normal EM gun. The magnetic field is due to the current flowing through the leading armature. The leading armature acceleration force is expressed by:

$$F_\ell = I_\ell \ \omega \times B_\ell, \qquad (2)$$

where B_ℓ = magnetic flux density imposed by current to the leading armature, on the leading armature, and

I_ℓ = leading armature current.

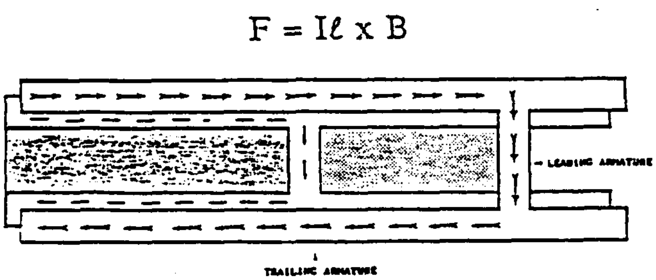

Fig. 3. Magnetic flux on leading and trailing armature is not equal (arrow size indicates current magnitude).

The magnetic field imposed on the trailing armature is due to the current to the trailing armature plus the magnetic field due to current to the leading armature. The force on the trailing armature is expressed as:

$$F_t = I_t \ \omega \times [B_t + B_{t\ell}], \qquad (3)$$

where B_t = magnetic flux density imposed by current to the trailing armature, on the trailing armature,

$B_{t\ell}$ = magnetic flux density imposed by the current to the leading armature, on the trailing armature, and

I_t = trailing armature current.

Examination of (2) and (3) reveals that to obtain equal forces on the leading and trailing armatures, the currents in the leading and trailing armatures must be unequal. In fact, to obtain equal forces the split of the total current is about 70% to the leading and 30% to the trailing. This result is derived from the fact that the magnetic flux $B_{t\ell}$ is about twice B_ℓ for teh 70%-30% current split.

CURRENT DISTRIBUTION CONTROL

Achieving the necessary leading and trailing current distribution cannot be accomplished in a normal railgun consisting of two conducting rails and similar armatures. Current will share depending on the resistance of the two paths. Most of the current would flow through the trailing armature. The required current distribution can be achieved by properly selecting the electrical impedance of the components in each circuit. These components are: 1) armatures, 2) rails, and 3) power supply. We evaluated all three methods for current control and determined that current distribution control by using separate power supplies is the most advantageous.

Controlling current distribution by connecting each rail segment to a separate power supply is the simplest and most flexible method. With this method, the armature impedance is unimportant. Both metal and hybrid armatures can be used, and transition of one armature does not affect the current distribution. The disadvantage is that two separate power supplies are required. Modular power supplies are ideal for this application. This is the method that we selected to use for demonstrating the multi-armature launch technique.

TESTING THE MULTI-ARMATURE AND MULTI-RAIL DESIGN

We constructed a barrel and the required power supply interfaces and tested the launcher by launching long rod projectiles to high velocities. A description of the launcher, launch packages, and test results follows.

Launch Package

A photograph of a typical launch package is shown in Fig. 4. The projectile was a tungsten rod with an L/D ranging from 20 to 40. The armature and sabot functions were integrated into one component. We elected to use metal armatures for this application. The launch package had two armatures (a leading and a trailing). The leading armature was composed of two halves; a top leading and bottom leading. Each half was powered by a separate rail pair. The trailing armature was powered by the current from the center rail. Current in each

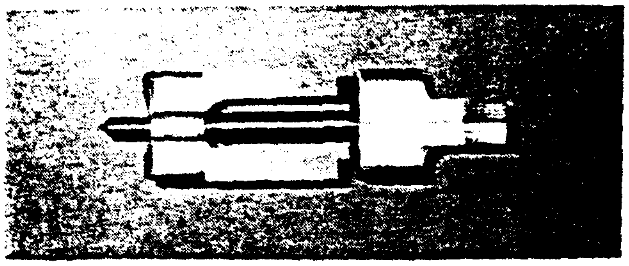

Fig. 4. The launch package had two armatures powered independently.

rail pair was about equal.

Barrel

We designed and constructed a 30 mm square bore EM gun barrel with three rail pairs. The EM gun barrel is shown in Fig. 5. The rails were insulated from each other with a 1/16 inch thick G10 insulator. The three rails were pinned together along the length of the bore with nylon pins. The pins were spaced about 18 inches apart. The rail spacing was maintained with a 30 mm G10 insulator. We used a 3 m gun for most of our tests. The rails were enclosed with a stainless steel laminated structure.

5. We built and tested a 30 mm square, three rail pair EM barrel.

The barrel operated extremely well. The inductance gradient was about 0.4 micro-henry per meter. We were able to independently power each rail pair throughout the tests. The straightness of the barrel and, in specific, the straightness of the middle rail was not as good as we would have liked. A better scheme to attach the middle rail is needed for future testing. The details of the barrel performance is described in another paper presented at this conference by the authors [3].

Interface

We modified our existing power supply-gun interface to accommodate the need to power the armatures independently. We built an interface which allowed us to provide 5/8 of the total current to the leading armature and 3/8 of the current to the trailing armature. This was possible because of the modularity of the power supply. A photograph of the gun interface is shown in Fig. 6. This top view of the interface shows two plates, one feeding the trailing armature rail and one feeding the leading armature rails. This interface performed extremely well. We were able to maintain separate power to the armatures.

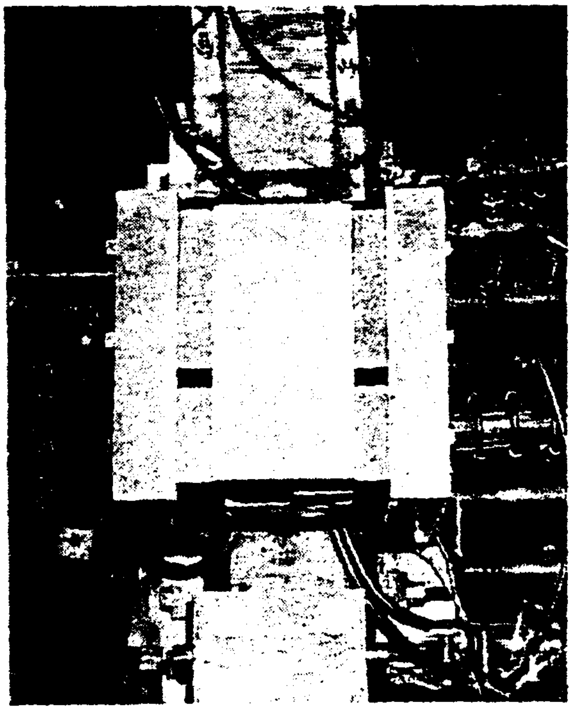

Fig. 6. Current was independently supplied to each rail pair.

Launch Results

We conducted a total of 18 tests during the development and demonstration testing of the multi-armature, multi-rail launch system. The test parameters are presented in Table 1. The launches were conducted with tungsten rods with an L/d ranging from 20 to 40. The total current levels ranged from 500 kA to 1 MA. The rod mass ranged from 60 to 120 g. The launch package mass ranged from 160 to 260 g. The highest successful launch velocity achieved was 1200 m/s. Typical current, muzzle voltage, and velocity traces are shown in Figs. 7—12. These are for a launch package of 175 g. Fig. 7 shows the total current as well as the leading and trailing armature current during the shot. Fig. 8 illustrates the current split among the armatures. Note that the current split remained constant throughout the launch. The muzzle voltage traces of each rail pair are shown in Figs. 9, 10, and 11. Fig. 9 is for the top leading armature, Fig. 10 is the muzzle voltage of the bottom leading armature, and Fig. 11 is for the trailing armature. Note that all three armatures contacts remained metal-to-metal contact throughout the launch. The average velocity is shown in Fig. 12. The velocity was computed from the B-dot data. The post-test observation and B-dot data indicated that the launch package remained intact throughout the launch.

In this program, we successfully demonstrated the feasibility of using a multi-armatures and rails concept to launch long rods to high velocities. This methodology has the potential of achieving high velocity and high efficiency launches (low parasitic mass). Higher velocities could not be achieved with this present system because of in-bore balloting caused by rail misalignment and lack of sabot support of the rods.

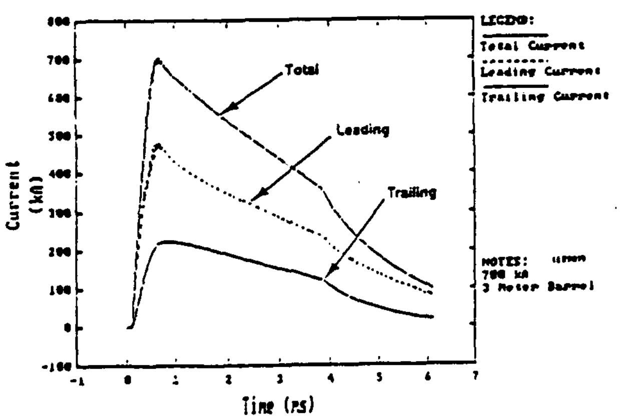

Fig. 7. Typical rail current traces for multi-armature railgun.

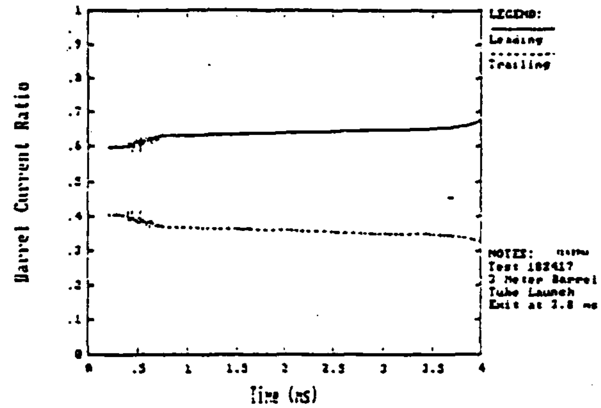

Fig. 8. Current split remains constant throughout the launch.

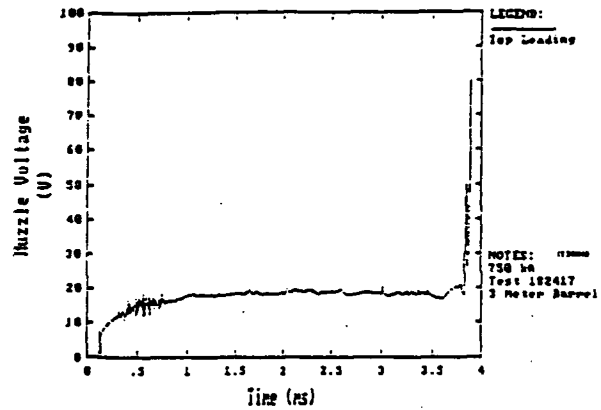

Fig. 9. Top leading muzzle voltage.

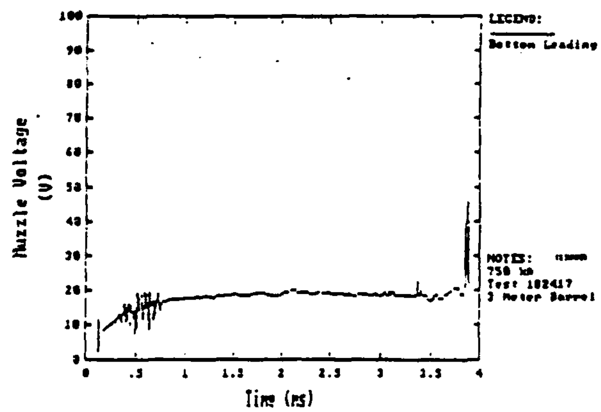

Fig. 10. Bottom leading muzzle voltage.

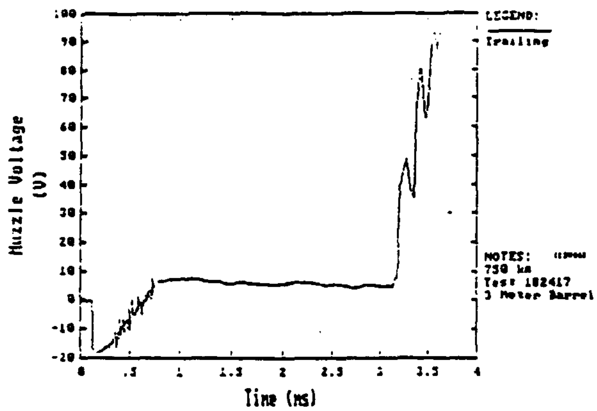

Fig.11. Trailing muzzle voltage.

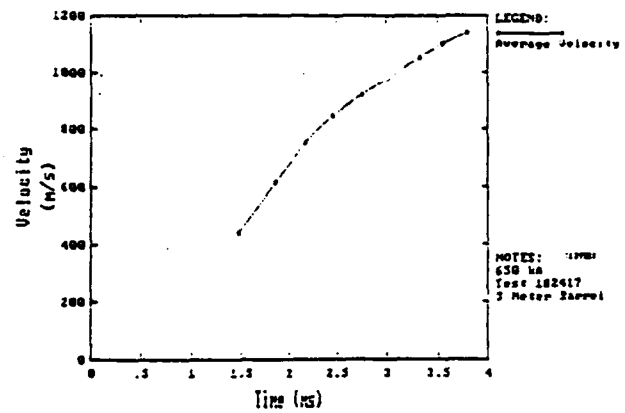

Fig.12. B-dots are used to compute average velocity.

TABLE 1. LONG ROD LAUNCH SUMMARY

Test No.	L/D	Peak Current (kA)	Barrel Length (m)	Peak Velocity (m/s)	Armature Mass (g)	Rod Mass (g)	Comments ND = No Data NT = No Transitioning NC = No Current
82401	N/A	780	2.8	ND	163.0	N/A	BJ bank checkout, 50 mm, single rail test
82402	30	500	2.8	650.0	97.3	95.1	Successful launch
82403	40	500	2.8	880.0	97.0	126.0	Crosspiece of trailing armature broke
82404	40	500	2.8	750.0	97.0	126.0	Crosspiece of trailing armature broke
82405	40	700	2.8	911.0	138.6	122.4	Rod broke in gun
82406	30	750	2.8	886.0	138.9	89.8	Trailing arms dug into rail
82407	20	750	1.0	1317.0	113.8	64.2	Successful rod launch
82408	30	750	2.8	1478.0	113.7	93.0	Predicted velocity was 1100 m/s
82409	20	300	1.0	0.0	112.4	64.1	Stationary test, measure B on trailing arms
82410	20	200	1.0	0.0	113.7	64.1	Repeat of Test 09 using CJ bank
82411	20	150	1.0	0.0	113.7	64.1	Repeat of Test 10 at lower current
82412	20	100	1.0	0.0	113.7	64.1	Only leading rails powered
82413	20	60	1.0	0.0	113.7	64.1	Only trailing rails powered
82414	20	750	2.8	960.0	109.36	97.32	Rod broke 2 mm from breech
82415	20	750	2.8	1120.0	95.9	64.5	Successful rod launch
82416	30	750	2.8	1640.0	195.6	114.9	Armatures exited ahead of rod
82417	30	650	2.8	1138.0	95.8	75.3	Successful tube launch
82418	20	900	5.5	1693.0	134.3	82.4	Rod broke early on

CONCLUSION

Based on our development work, we demonstrated that EM guns can be designed to launch very long projectiles by distributing the launch forces along the length of the rod via multiple armature-rail pairs. This method takes advantage of the unique features of the railgun (controlling forces by controlling current), and can be exploited to achieve hypervelocity launch of long rods. Future work must incorporate sabots which provide better external projectile support and improve rail construction to provide higher precision bore.

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